BBH population

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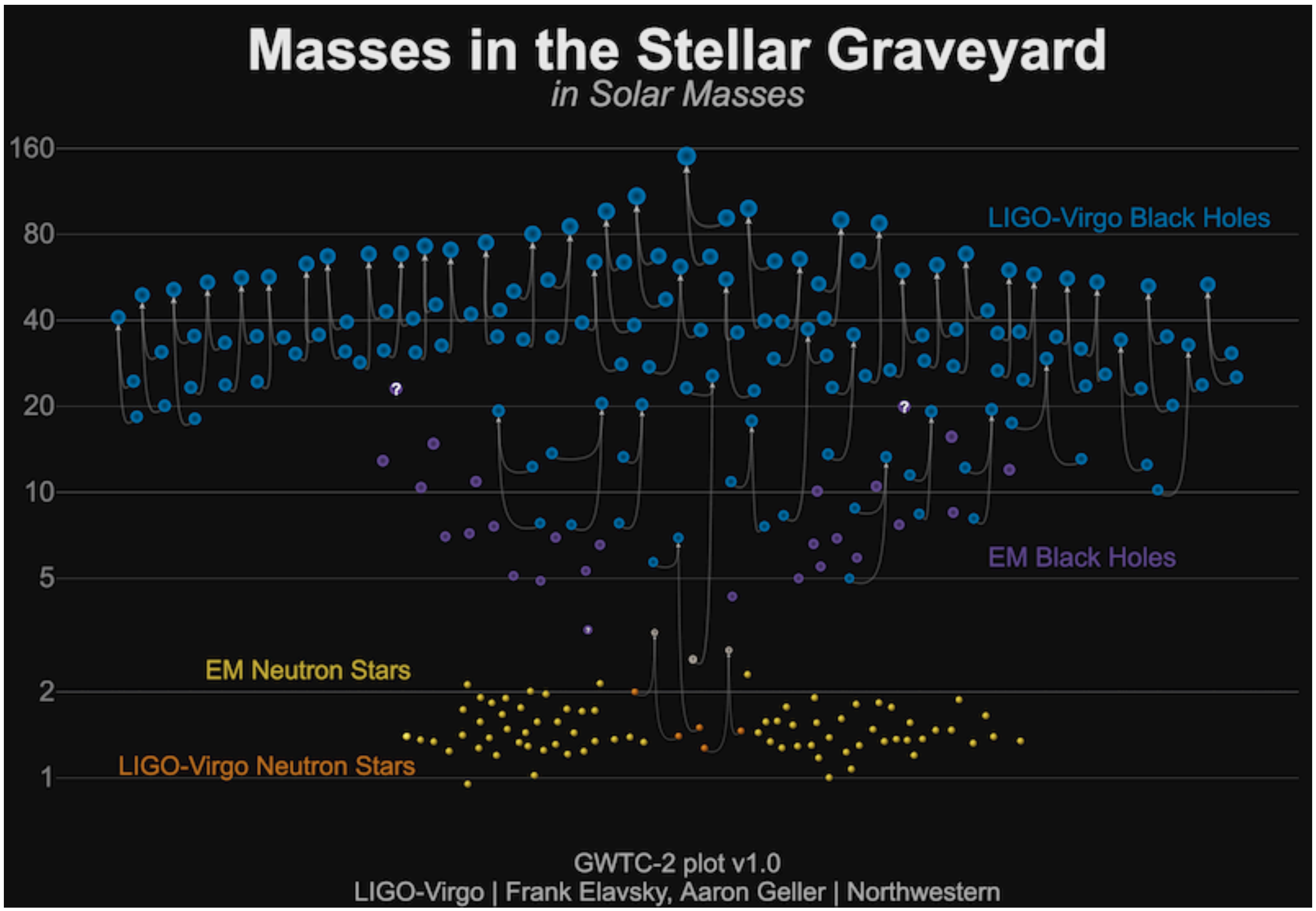
Outline

- Introduction/motivation
- Results from independent population analysis. Focus on spin.
- GW151226 bimodal posterior.

Masses and spins of individual Black Holes

The BHs observed by LIGO are surprisingly heavy. They are both heavier than the BH in binaries in our own galaxy and some of them seem heavier than what our theoretical calculations seem to allow. They also seem to be spinning slowly.



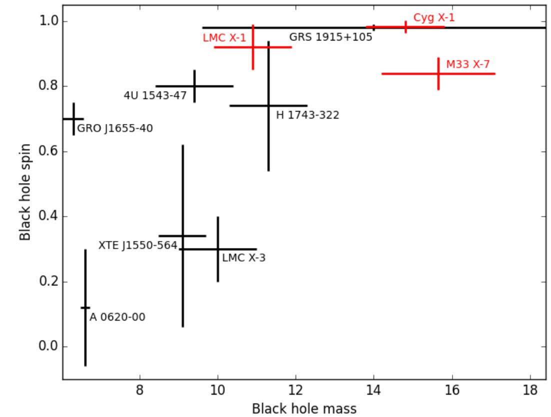


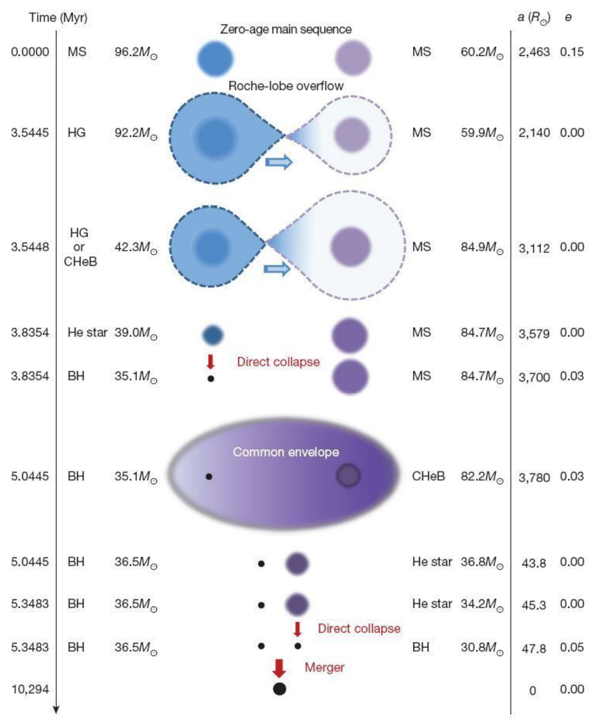
Figure 1. Masses and spins for 10 black holes with approximate error bars. The three high-mass-X-ray-binary systems, LMC X-1, Cygnus X-1 and M33 X-7 are indicated by names above the line and in red online.

Nielsen 1604.00778

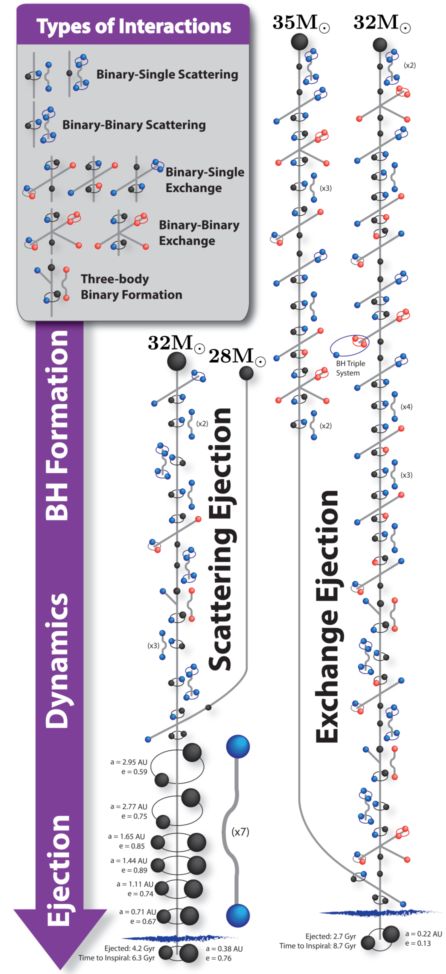
Cygnus X-1 contains a 21-solar mass black hole – implications for massive star winds

James C.A. Miller-Jones,[1*] Arash Bahramian,[1] Jerome A. Orosz,[2] Ilya Mandel,[3,4,5]
Lijun Gou,[6,7] Thomas J. Maccarone,[8] Coenraad J. Neijssel,[3,4,5] Xueshan Zhao,[6,7]
Janusz Ziółkowski,[9] Mark J. Reid,[10] Phil Uttley,[11] Xueying Zheng,[6,7]
Do-Young Byun,[12,13], Richard Dodson,[14] Victoria Grinberg,[15] Taehyun Jung,[12,13]
Jeong-Sook Kim,[12] Benito Marcote,[16] Sera Markoff,[11,17] María J. Rioja,[14,18,19]
Anthony P. Rushton,[20,21] David M. Russell,[22] Gregory R. Sivakoff,[23]
Alexandra J. Tetarenko,[24] Valeriu Tudose,[25] Joern Wilms[26]

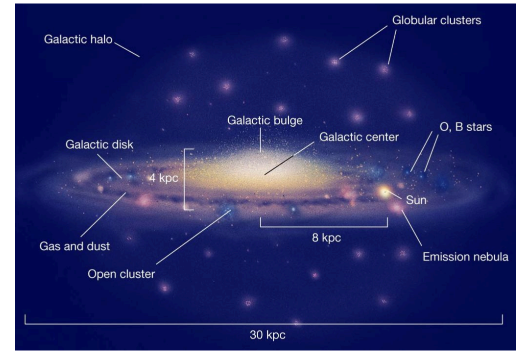
Formation channels



Belczynski et al. 2016



Rodriguez et al. 1604.04254



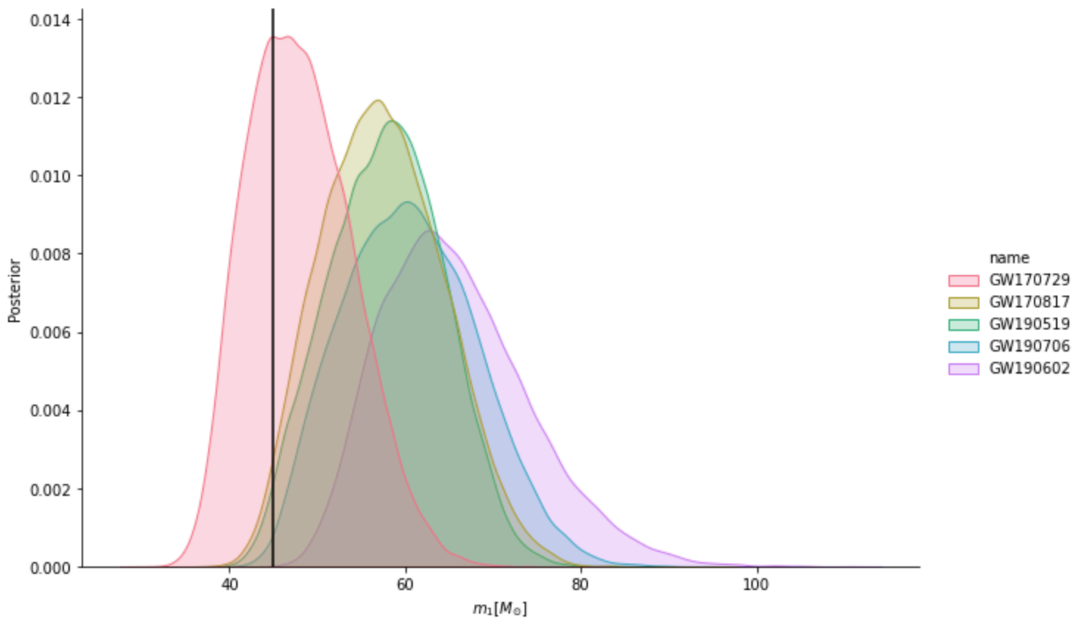
- Rate
- Masses
- Spin
- Eccentricity

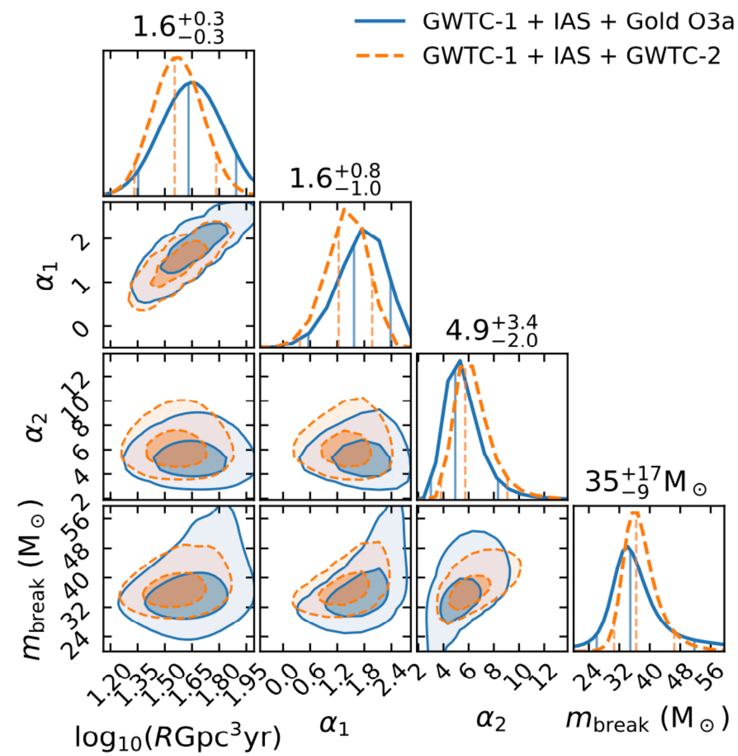
There already is interesting spin information

PE run characteristics

- Precession and higher modes for all systems using IMRPhenomXPHM approximant (modes=(2,2)(2,1)(3,3)(3,2)(4,4). Sampler: PyMultiNest (LVC population paper did not reanalyze the O1 & O2 events, used published posteriors run with IMRPhenomPv2. Used HM for O3a)
- Uniform prior in chi effective.
- Population analysis following Roulet et al.

High Mass End





There are several examples of events with masses above the pair instability threshold.

We reproduce LVC results.

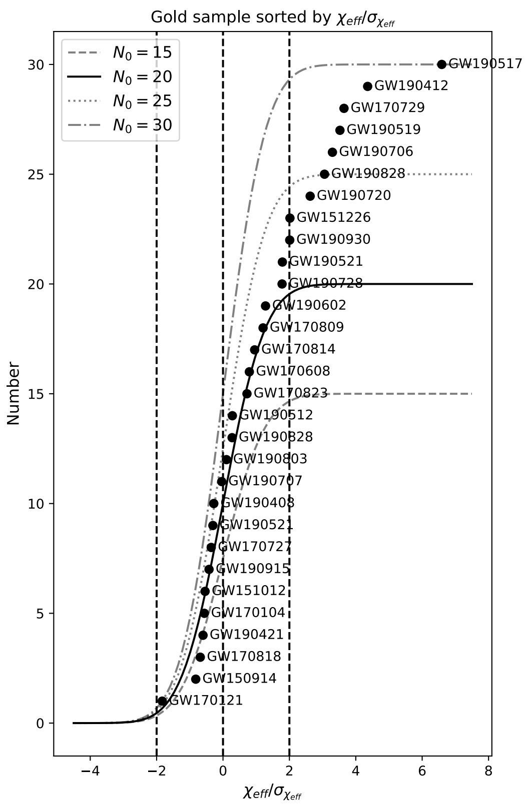
Note that there is already one event O2 (GW170812) in the IAS sample. GW170729 was also heavy although consistent with the cut-off. It was marginal in the LIGO pipeline but was completely above the background in our search.

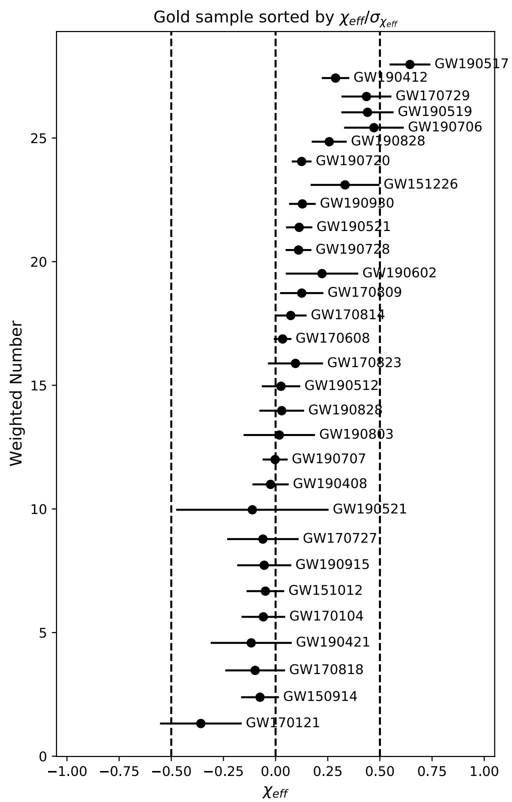
Spin expectations

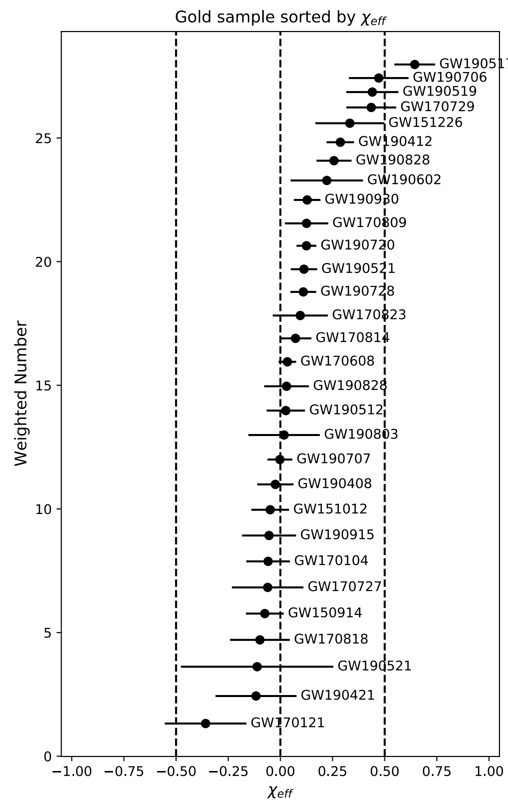
- Black holes are born with low spin
- In binary systems, prior to the formation of the second black hole, tides can spin up the WR star and lead to high spin
- Second generation black holes have significant spins
- In the field binary channel, the is a preference of the spin to be aligned with the orbital angular momentum
- In dynamical channels the spin orientation is random

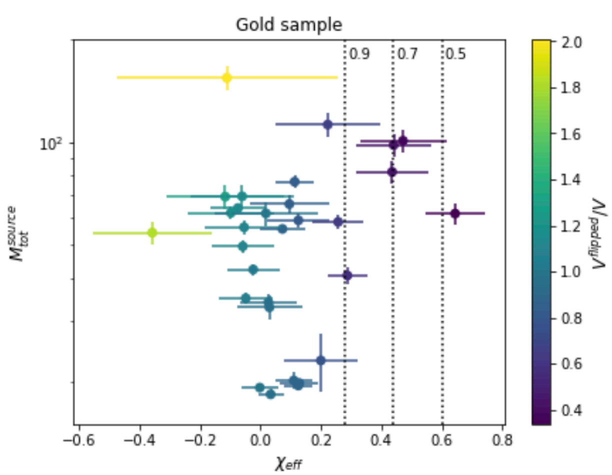
Spin measurements

$$\chi_{\rm eff} = (m_1\,\chi_{1z} + m_2\,\chi_{2z})/M$$



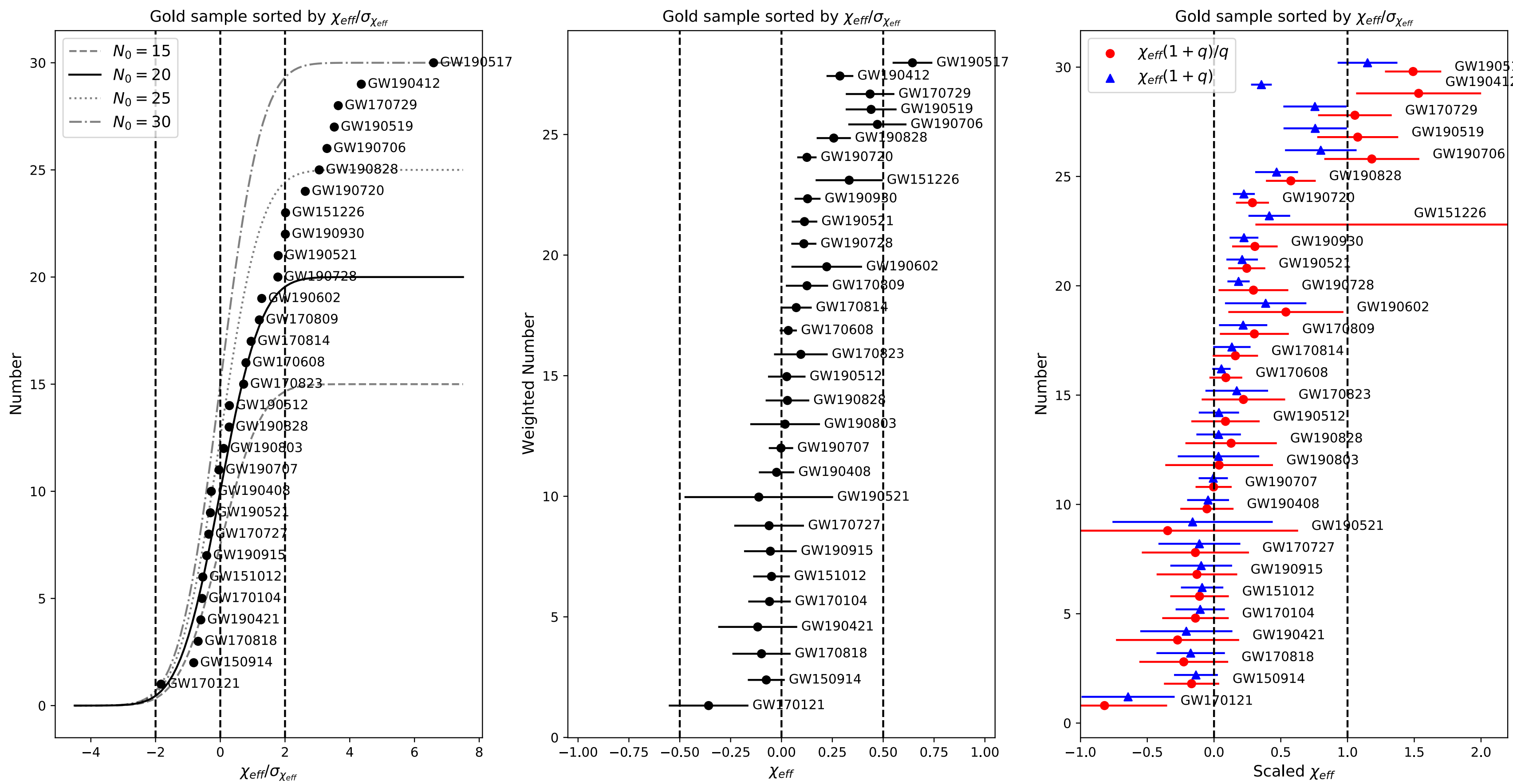






- Distribution not consistent with negligible spin
- Clear tail on the positive side, of order 1/3 events
- No evidence of negatively chi effective
- Volume effect does not seem to explain the asymmetry

Naive tides

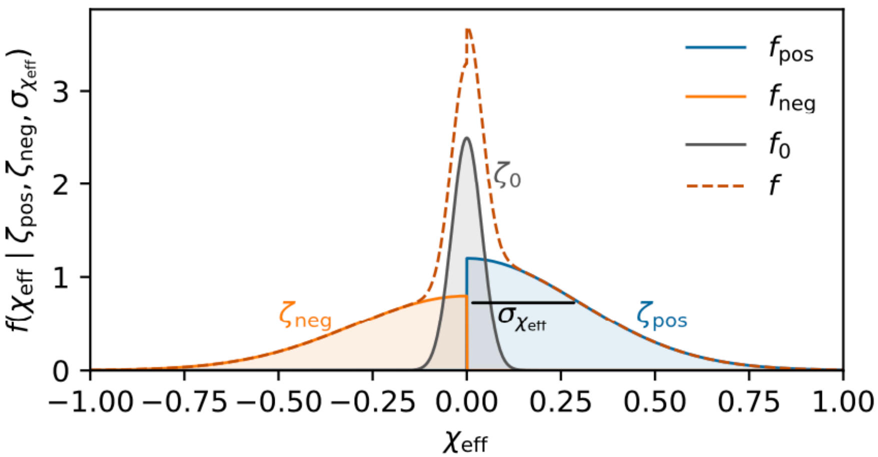


Several of the events with non-zero chi effective have relatively small values. They are inconsistent with the assumption that either primary or secondary are maximally spinning while the other BH does not spin.

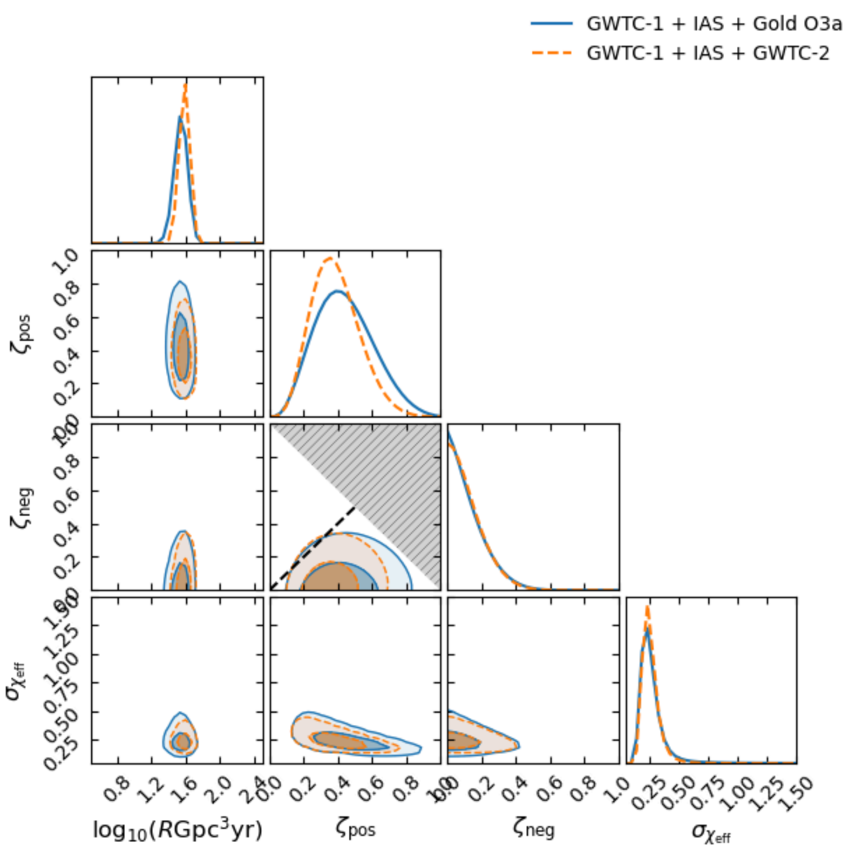
Basic summary

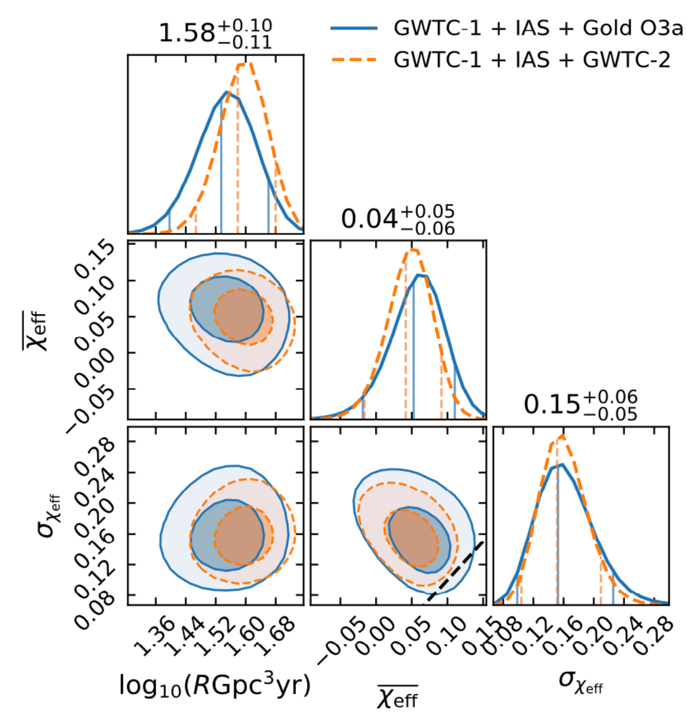
- Spins are small but the distribution is not consistent with no spin.
- All the significant detections are on the positive spin side (small caveat, positive spin events are louder but this does not seem enough). This points to a significant contribution of the binary channel
- There is no evidence for negative spin. (Absence of evidence not the same as evidence of absence)
- Several of the spins that are significantly different from zero are still small. Not very consistent with the naive tide scenario

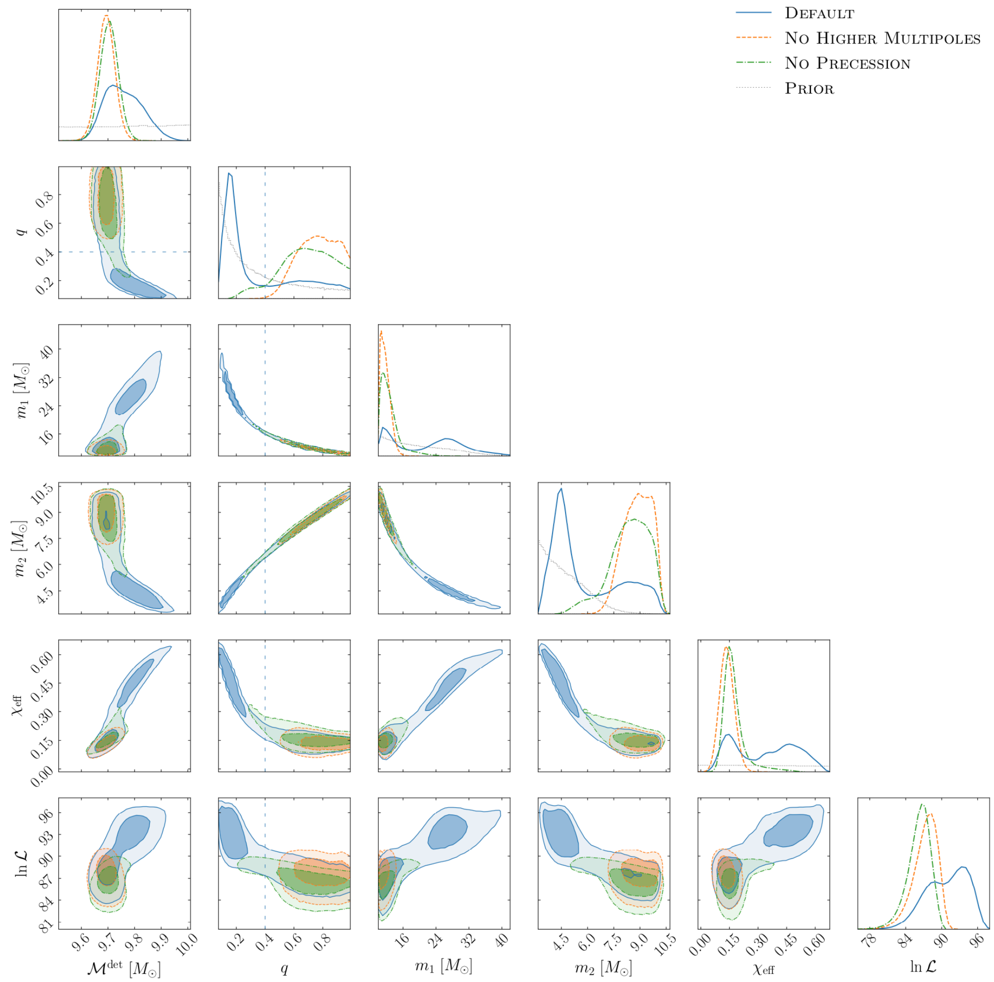
Hierarchical Bayesian model



- Simple models reproduces conclusions above
- If we use a Gaussian pdf we reproduce LVC results. Width of Gaussian larger than mean, so model has negative chi effective tail.
- We need more data and we have to be very careful with these type of analysis.





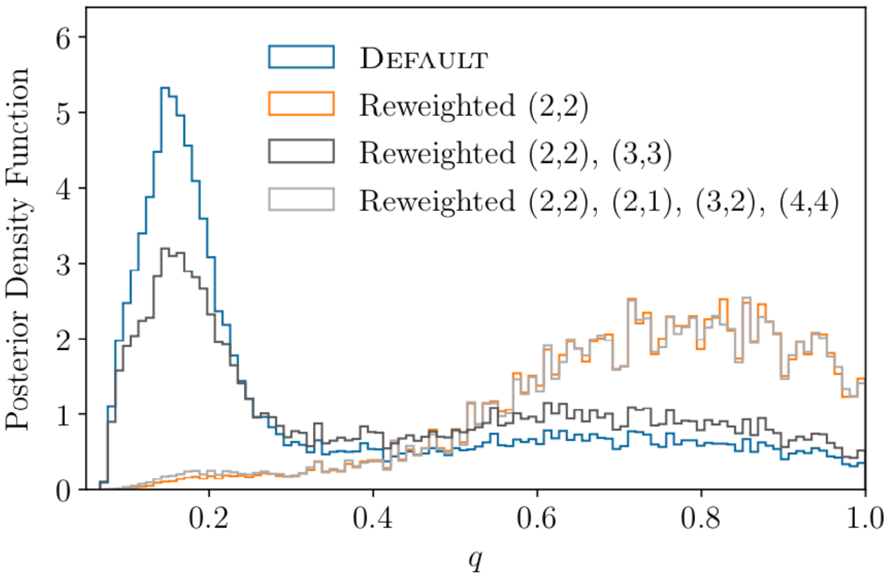


	Low$-q$ Mode	High$-q$ Mode	No Higher Multipoles	No Precession
Detector-frame chirp mass, $\mathcal{M}^{\rm det}$ $[M_\odot]$	$9.79^{+0.10}_{-0.08}$	$9.69^{+0.06}_{-0.06}$	$9.69^{+0.05}_{-0.05}$	$9.70^{+0.06}_{-0.06}$
Mass ratio, $q = m_2/m_1$	$0.16^{+0.17}_{-0.08}$	$0.7^{+0.2}_{-0.2}$	$0.76^{+0.20}_{-0.23}$	$0.7^{+0.2}_{-0.3}$
Primary source mass, m_1 $[M_\odot]$	26^{+11}_{-9}	$12.1^{+3.4}_{-1.9}$	$11.4^{+2.4}_{-1.3}$	$12.0^{+5.6}_{-1.9}$
Secondary source mass, m_2 $[M_\odot]$	$4.5^{+1.5}_{-0.9}$	$8.4^{+1.5}_{-1.6}$	$8.8^{+1.1}_{-1.4}$	$8.4^{+1.5}_{-2.4}$
Total source mass, M $[M_\odot]$	31^{+10}_{-7}	$20.7^{+1.7}_{-0.8}$	$20.5^{+0.9}_{-0.6}$	$20.6^{+3.2}_{-1.0}$
Effective aligned spin, $\chi_{\rm eff}$	$0.44^{+0.15}_{-0.20}$	$0.14^{+0.08}_{-0.07}$	$0.13^{+0.07}_{-0.06}$	$0.15^{+0.15}_{-0.06}$
Inclination angle, $\lvert\cos\theta_{\rm JN}\rvert$	$0.94^{+0.04}_{-0.09}$	$0.84^{+0.14}_{-0.29}$	$0.84^{+0.14}_{-0.29}$	$0.79^{+0.19}_{-0.37}$
Luminosity distance, D_L [Mpc]	457^{+90}_{-119}	473^{+129}_{-147}	469^{+126}_{-143}	459^{+156}_{-174}
Source redshift, z	$0.096^{+0.018}_{-0.024}$	$0.10^{+0.02}_{-0.03}$	$0.10^{+0.02}_{-0.03}$	$0.10^{+0.03}_{-0.03}$
Log likelihood, $\ln\mathcal{L}$	$93.0^{+3.0}_{-3.9}$	$87.4^{+2.8}_{-4.1}$	$87.5^{+2.5}_{-4.1}$	$86.4^{+2.5}_{-3.8}$
Log prior, $\ln\pi$	$29.8^{+0.4}_{-0.6}$	$29.7^{+0.6}_{-0.9}$	$29.8^{+0.6}_{-0.9}$	$+29.7^{+0.8}_{-1.3}$
Fractional sample number in Default	65.3%	34.7%	–	–

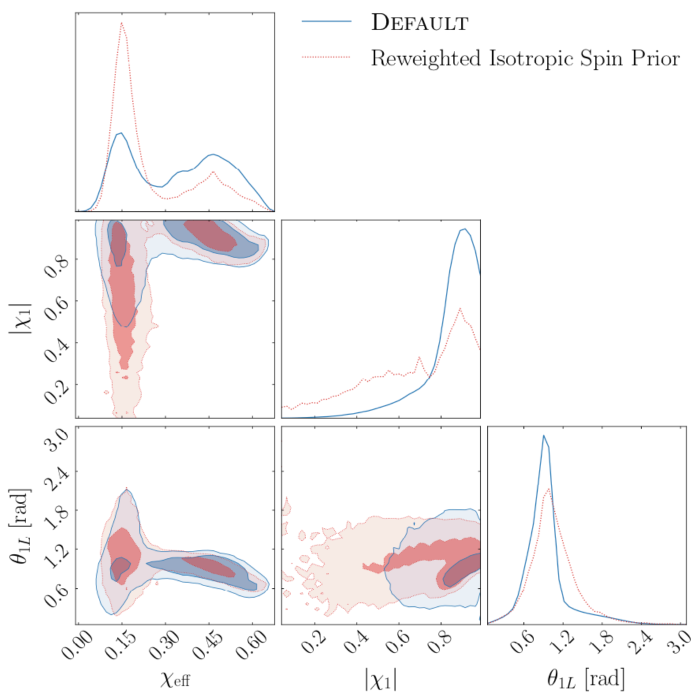
A boxing day surprise: GW151226

- Bimodal posterior
- 65% of the samples are in a low mass ratio peak. Similar to GW190412?
- Low q peak has 6 points higher likelihood. These are not two separated peaks in the likelihood, but the result of a competition between likelihood and parameter.
- To find these solution both higher modes and precession are necessary.
- Is this a more general phenomena? Six point in log likelihood is a large number, should we be worried about prospects of identifying these type of systems?

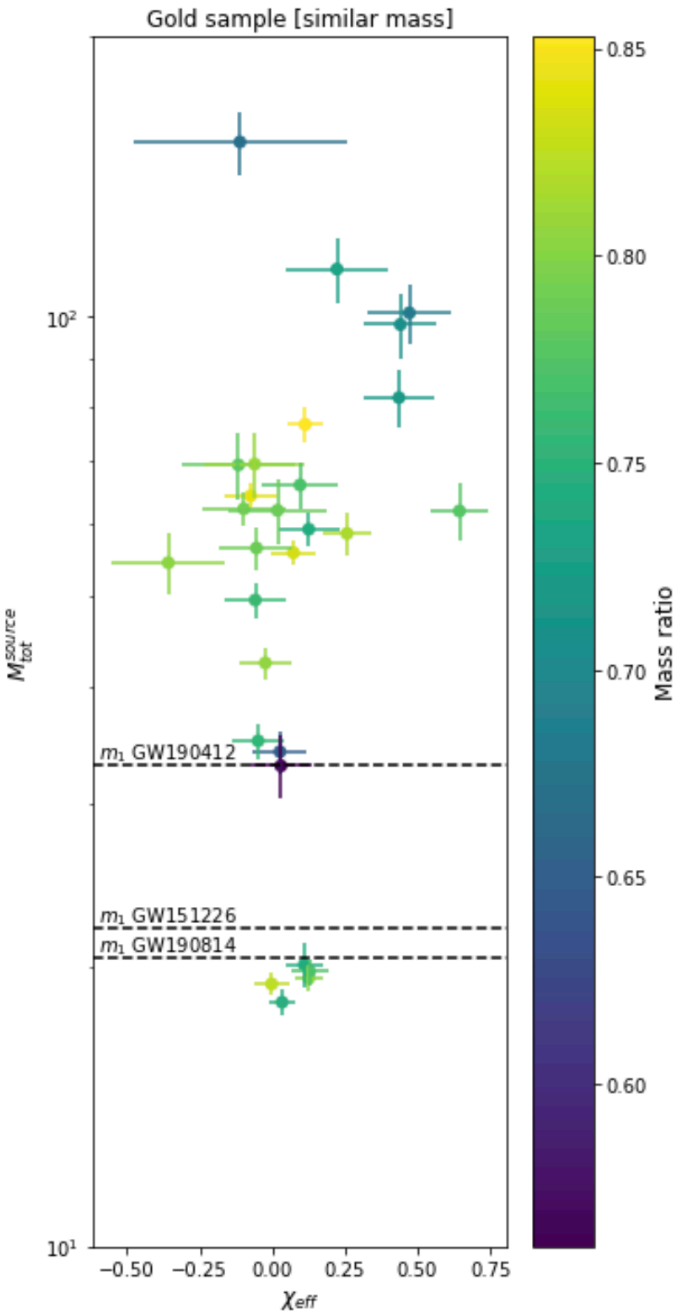
HM and misaligned spins



- 33 mode is the needed to see the low-q peak
- Precession is needed
- Primary spin is consistent with a~0.7



Other extreme mass ratio examples



- GW190412 and GW152626 Evidence of precession, dynamical channel?
- GW190814 is not spinning. Very well constrained.
- Could GW190412 and GW152626 be secondaries?
- Must be a very efficient as we do not see many 'progenitors' events and there is no substantial selection effect difference.

Summary

- The origin of BH binaries is an astrophysical puzzle. We might be able to solve it in the near future by studying the properties of individual systems.

- Puzzling results in the heavy and light ends of the BH mass function. Spin distribution begins to be informative.

- Spin distribution does not seem symmetric. There is no evidence for negative chi effective. Field binary channel seems to play an important role.

- GW152626 has bimodal posteriors. The low q solution requires higher modes and precession. Even though the low-q solution has a higher likelihood (six points) phase space effects prevent an unambiguous determination. Is this more general? Should we worry?